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High Voltage Power Distribution Network Insulator Fault Monitoring Using IoT Technologies

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Abstract: The most common method of detecting insulator faults to date requires trained personnel to manually inspect a large number of insulators in a variety of locations and positions. This is a relatively simple task if there's a road next to the HV grid. When the terrain isn't so easily accessible, the difficulty of detection increases exponentially. This is where IOT technologies come in. A Croatian team consisting of the company Callidus Group and the Faculty of Electrical Engineering, Computer Science and Information Technology in Osijek (FERIT) is developing a LoRa-based tracking device. The device (consisting of several sensors, a control unit, and a communication unit) is still in the development phase, which means that each sensor is being tested both in a laboratory and in an active distribution network. The device is expected to have a lifespan of about ten years when attached to the insulation. Under the given conditions, LoRa has shown its full potential with its low energy consumption and long range. Theoretically, Lora communication could reach a range of 10 km. Using LoRa devices instead of manual and optical methods is a resource and time-saving method.

Keywords: *IoT, LoRa, LoRaWAN, high voltage network monitoring system*

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I. INTRODUCTION

As the number of high-voltage power lines increases, so does the number of insulators that are installed on them. Since these insulators are located in many areas with varying conditions, there are almost countless ways in which failures can occur, but some of these failures occur more frequently. These failures include, for example, cracks in the insulators caused by bad weather. As shown in Figure 1.

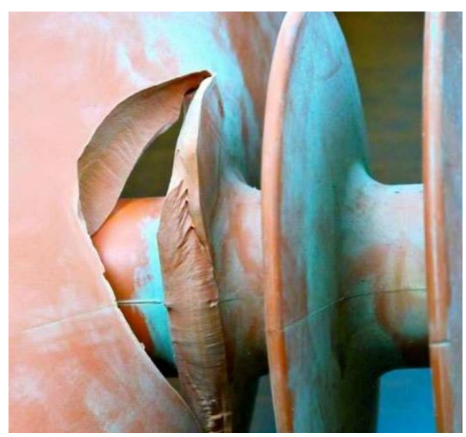

Fig. 1. Insulator damaged due to high winds [1]

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Failures caused by polluted air or acid from the droppings of certain bird species, on the other hand, are a little harder to imagine but do occur, as shown in Fig. 2.

Fig. 2. Highly conductive bird droppings[1]

Of course, there's also the wear and tear of the materials from which insulators are made, but the manufacturing defects that have occurred are small enough to go unnoticed but large enough to cause a malfunction [1]. In addition, some of the defects, such as air contamination, can be present all the time and permanently reduce the insulator's ability to insulate by causing alternating conductive, dry, and wet areas on the insulator [2].

In order for the power grid to function efficiently and for end-users not to be left without electricity, faults in the insulator must be noticed and repaired in time. Unfortunately, there's not yet an effective method to detect all types of faults. In addition, the safety of the personnel carrying out these repairs must be taken into account.

By far the most common method for detecting malfunctions is a visual inspection. This method is also the most effective, as each insulator is usually inspected in person. This method can be done from the ground, from a helicopter, or from a truck basket, usually with the aid of binoculars. Visual inspection requires personnel to approach each insulator, which is a major problem if the power grid pylon is located off the road, in a forest, or on an inaccessible mountain. Somewhat less common methods include IR thermography, UV, acoustic, or E-field inspection [3].

Recently, remote inspection methods for insulators have also become available. These methods have come to the fore with the advancement of smart technologies and the IoT world. These technologies enable timely detection and increase the safety of the personnel who've to find and fix the fault. In order for everything to function according to modern requirements, new monitoring systems must be durable, which means they must've minimal energy consumption but also be very reliable. The right candidate to meet these requirements is the LoRa-based device [4].

II. RESEARCH AND DEVELOPMENT OF SYSTEMS FOR MONITORING HIGH-VOLTAGE ROUTES USING IOT TECHNOLOGIES

The applicant's project aims to develop a new technology that will form the basis for the construction of a new company product or solution for monitoring high-voltage power lines, more specifically, a digital system for detecting breaks in high-voltage insulators. High-voltage insulators are used in various segments of the power industry, but the applicant's focus is on insulators from 3kV to about 1000 kV (primarily in the 10kV-100kV range), which are used in power transmission and distribution and account for about a third of the global insulator market.

The goal is to develop breakthrough detection devices and build a cloud system that reports in real-time which insulator has failed to minimize downtime and replacement costs, enable maintenance of insulators and enable monitoring of other important aspects of the transmission line for which there are no instruments in most transmission lines today (wire breakage, lightning strike). The project is being carried out in industrial research and experimental development phases. The project leader is the company Callidus Group from Zagreb, Croatia, while the Faculty of Electrical Engineering, Computer Science, and Information Technologies in Osijek is the project scientific partner of the project. The project is co-financed by the European Structural and Investment Funds [5, 6].

A. *Development*

The sensing device is designed as an independent system, completely isolated for reasons of safety of use and longevity, consisting of containing three basic units; sensors, control system, communication system, and battery. The idea of the device is based on the fact that physical damage to the insulator's body causes changes in the electric and magnetic fields around the insulator. These field changes aren't easy to observe or measure. Therefore, it's necessary to develop a systematic approach to monitoring and analyzing the data that the sensors can collect. The operation of the sensor must be optimized by the control system so that it doesn't consume too much energy and is only switched on when it's triggered (longer battery life is basically the same as the life of the particular sensor). This type of management requires that the sensors are monitored as a multitude of control points this is the task of LoRa communication.

Fault detection is based on two basic triggers. The first is that during normal operation, three-phase power line sensors located on the same pylon should respond the same way over a longer period of time, which can then be detected by comparison (due to a fault, a particular sensor should start giving different readings e.g. after an insulator failure). This is important if there's major insulator damage. The second trigger is power system transients monitoring (transient of current and voltage waves), which occurs when a larger load or a smaller atmospheric discharge is switched on. Significant changes in electromagnetic field levels then occur and consequently, potential faults can be detected.

The LoRa network architecture is basically built in a star-to-star topology, connecting LoRa endpoints to servers via gateway devices, usually bidirectionally.

The LoRaWAN used in Europe is in the 868 MHz frequency band. It uses 8 or 16 channels, with 8 channels being the standard, but some gateways can work with 16 channels if needed. Multiple channels increase the ability to receive data from many different devices simultaneously, which is necessary when an entire network consists of hundreds of LoRa endpoints.

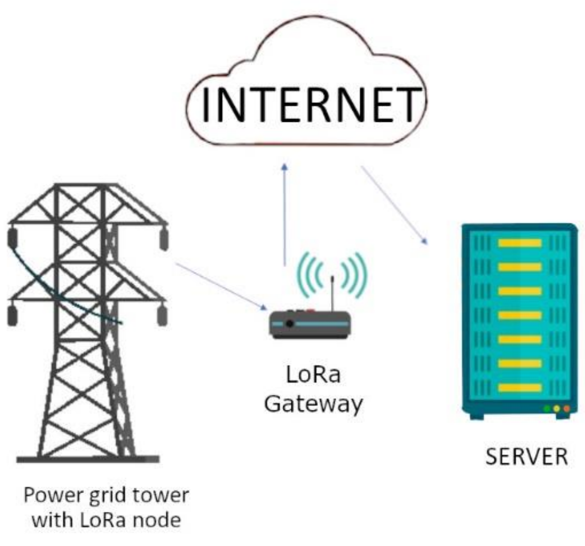

Fig. 3. The LoRa communication network

A gateway is a device that converts LoRa signals into an IP network. The gateway's job is to receive all packets sent by the devices (LoRa endpoints) in the field and forward them to a server, the network server in the LoRaWAN. The network server processes this data and prepares it for further analysis of the LoRa network on the cloud server. The final step in the network is to process and analyze the signals.

The gateway is basically a very simple device that's the task of translating data from LoRa signals into packets used in computer IP networks [7, 8].

There are many different manufacturers and models of gateways. In principle, all gateways from the different manufacturers have the same basic functions as far as LoRa is concerned. Most have additional features related to "backhaul" connectivity (Wi-Fi, Ethernet, GSM, VPN), a number of channels (8 or 16), and other additional features that can be closely tied to a product (e.g., monitoring of the gateway on the system by the manufacturer). In this project, The Things Outdoor Gateway was used most frequently.

Gateways can be placed anywhere it's possible. There are indoor and outdoor gateways, depending on where they're installed. Outdoor gateways are naturally equipped with slightly more powerful hardware because they're used in places that require a longer range, while indoor gateways are used for some indoor areas of the building. Each outdoor gateway has the option of powering itself via PoE, while indoor gateways are usually powered directly via a power adapter [9, 10].

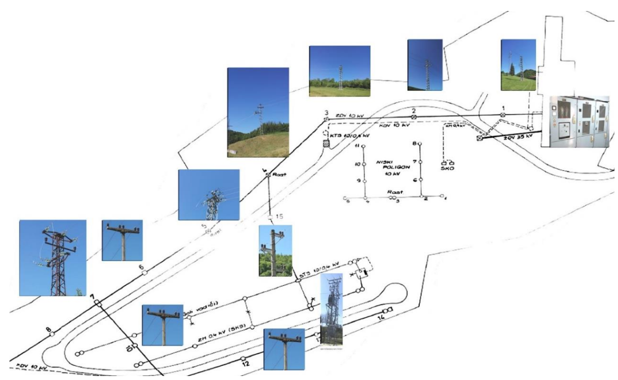

Fig. 4. HEP NOC center

B. *Field Tests*

The first test of the device was carried out at HEP NOC, a teaching and training center owned by Croatian Electricity Company, which has its own HV control and testing laboratory where insulation tools and personal protective equipment are regularly checked. It's an accredited laboratory with international certificates and is a perfect candidate to provide reliable results [11].

The HEP NOC has a field polygon with a variety of power grid pylons and insulator types Fig. 4 so that the final product of the project (sensing LoRa devices) can be tested for use in the full range of possible types of insulator chains and power grid pylons.

The first group of 20 test devices was brought to the HV laboratory to test them under real conditions. The gateway was placed no more than 10 meters away to test which devices are capable of communicating with the server in the presence of a high voltage (the sensors must be functional for up to 400kV). Fig. 5 shows how the devices were placed inside of the HV laboratory (part of the laboratory of HEP NOC), which is equipped to measure partial discharges up to 100 kV.

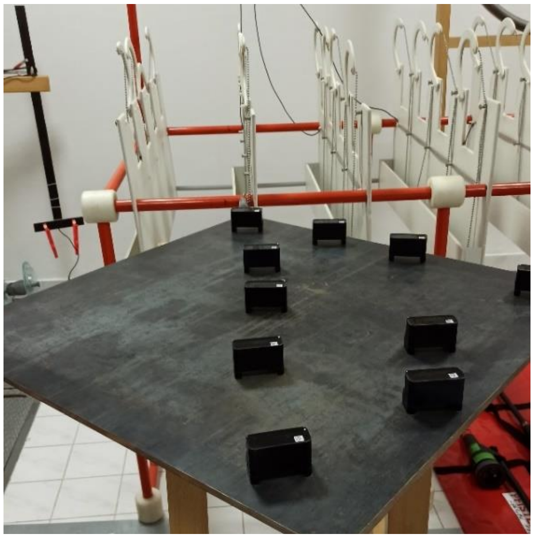

Fig. 5. Metal plate as zero potential planes for the simulation of partial discharges and arrangement of the tested devices

Of the 20 devices, 7 didn't send data to the server and were marked inoperable and removed from further testing. This part of the testing is needed to determine further large-scale testing for product manufacture. Each non-functional device was subjected to a detailed examination to determine what kind of fault was present (bad soldering, overheating during the protection process).

The field test was completed after confirming the data of the 13 remaining devices were received. After that, the teams approached a detailed analysis of the collected data, each in their institution. Further changes to the device communication were proposed, some of which were implemented by upgrading the entire product, and a second field test was conducted a few months later to confirm the product's functionality. In parallel with the field tests, numerical calculations (FEM in ANSYS software) were carried out to obtain a simulation of the electric and magnetic field surrounding the HV insulator parts while they were attached to the power line to determine the position where the device should be placed. Proper placement of the devices must be accompanied by correct adjustment of the sensors inside them and their calibration so that their readings match the detection of the electromagnetic fields at the actual position of the insulator chain Fig. 6 presents the contour of the electric field around single glass insulator chain parts.

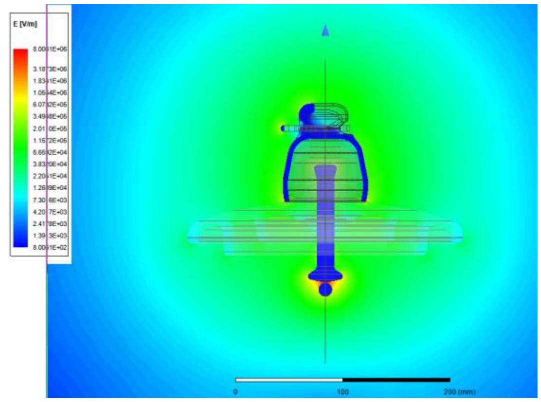

Fig. 6. FEM numerical analysis of electrical and magnetic fields around insulator chain parts

Finally, a test of the installation of sensor devices on real insulators on high-voltage pylons was carried out. Fig. 3 shows the variety of insulators and pylons types, and different types of locations were selected: suspended insulator, support insulator, power grid pylon with disconnecter, tension non-reinforced power grid pylon. Fig. 7 shows the way the device is attached to the insulator, and Fig. 8 shows the test grid in HEP NOC.

Fig. 7. Mounting of sensor devices using metal clips on the metal part of the glass insulator

The second field test of the sensor devices, which were attached to the isolators at various positions on the test site HEP NOC, was carried out after the devices had been adjusted and calibrated according to the analyses carried out earlier. In this part of the test, an attempt was made to simulate the transition of voltage and current waves power lines due to staggered short circuits using HV insulating rods. The short circuits were performed between the individual phases, between the phase conductors and earthing, and at different positions.

Fig. 8. Testing field of HEP NOC facility

During the test period, various weather influences (rain, fog) also occurred, which changed the distribution of the electric and magnetic fields near the insulator. Following the tests from the reference literature, some tests were also carried out after the insulator surface was soiled with mud and other characteristic deposits (which shortens the penetration path of stray currents on the surface of the insulator chain).

III. CONCLUSION

Maintenance is the main focus of the future development of any form of a technical system, and this also applies to power grid systems with transmission lines. One of the most common problems is the failure of the insulator, which paradoxically makes it the cheapest part of the system, but because of its multiplicity and importance requires constant investment in the development of monitoring and maintenance systems. The LoRa communication network, as one of the forms of a solution, has shown numerous advantages in terms of simplicity and long term use (efficient use of the low energy required for communication).

Humans' visual inspection is still the predominant and safe solution when the search for the fault location is sufficiently narrowed down. However, narrowing down the location of the fault falls into the realm of advanced communication systems and sensor networks, which are presented in this paper. The novel sensor being developed in this project should provide a low cost solution with a satisfactory level of accuracy with immense software and hardware upgrades. Two different approaches to fault detection are presented: Using response comparisons during normal operation under load and during significant transients. Further performing complex numerical calculations on the most realistic events will provide space for better sensor calibration as well as for upgrading the final product with new sensor types.

The next upgrade, which has even been tested on one of the prototypes, is a drop detector in the form of an accelerometer. The installation of such a sensor wouldn't have a significant impact on the manufacturing cost of the device or drastically shorten the battery life [12].

Lora is a part of the telecommunication technologies called LPWAN, i.e., Low Power Wide Area Networks, and as the name suggests, it was developed to meet the new need for long-range networks with low power consumption at the same time. With optical visibility and optimal conditions, especially in rural areas, communication can easily reach a range of 10 kilometers. Comparing all the sensors that the node contains, their consumption is negligible, which means that most of the energy is used for the already economical LoRa communication. With the current battery, the node can operate for about 10 years, which is a great result [13].

IV. ACKNOWLEDGMENT

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